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The Evolution of Concrete (Part 2): Unprotected in Humid Tropical Weather and Its Compression Strength

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Abstract

This paper discusses the unprotected concrete in the basement which has been neglected for 10 years. The purpose of this study was to determine the compressive strength and microstructural changes in unprotected concrete in the humid tropics. The research was carried out experimentally. It was a case study at the State University Hospital, Lampung University, Indonesia. The compressive strength and microstructure of unprotected concrete compared to concrete in the protected condition. The compressive test samples were taken with 4 core drills for each condition. The compression test data was processed by the Outlying method. The microstructure of the concrete was examined by scanning electron microscopy (SEM), and energy-dispersive X-ray (EDX). The results showed that the compressive strength of unprotected concrete was 65% of the compressive strength of protected concrete. There are Kalium (Potassium) compounds in unprotected concrete but not in protected concrete. Rain that enters the unprotected concrete makes Ca dissolve and the porosity increases. Oxidized Potassium in the air enters the concrete, increasing oxidation, and producing calcite. Calcite dominates the microstructure of unprotected concrete. Oxidation causes the pH to decrease and silica dissolves. This makes CSH and CH unstable. Ca bonds in unprotected concrete are more easily broken. The presence of Potassium and the hot air of the tropics makes the temperature in the concrete increase, the expansion of Al and calcite becomes greater and the microstructure of the unprotected concrete becomes complex. Cracks appear in the unprotected concrete microstructure. The inclusion of elements that are reactive to the concrete can make the concrete degraded.

Keywords: compressive strength, concrete, evolution, microstructure, tropical weather, unprotected
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1. Introduction

Concrete buildings can last 50 to 100 years or more. Due to its durability, most concrete buildings are demolished due to functional obsolescence rather than damage. However, under certain conditions, concrete undergoes weathering, this is due to chemical and environmental reactions. New climate challenges force a more careful look at the long-term performance and durability of building components and materials. Thermal stress due to daily temperature fluctuations and exposure to UV rays significantly damages the plaster and reduces its performance [Soudian *et al.* 2020].

With little or no organic content, concrete is resistant to decay or rust damage in hot and humid climates. Concrete, masonry, stucco, and all forms of concrete surfaces will be damaged by UV rays. Summer months, UV damage is accelerated. UV rays break down the polymers and other bonding chains in the concrete, causing the concrete to weaken over time. Over the years, this damage will produce dust or a fine powder that is visible to the touch, and will also cause cracking or chipping. This weakens the structure significantly and paves the way for more serious damage in the future. Any pigment or color on the surface of the concrete will also be damaged, causing the colors to appear faded [Plidek 2019].

Aging in a mildly acidic environment does not cause in any adverse effects and some cases, even positive effects are observed. This difference can be known from microstructural observations [Wasserman & Bentur 2006].

During its life cycle, concrete can capture CO_2 through carbonation. Carbonation takes up a share of the entire dam area, indicating the potential for CO_2 uptake. There were 155 cores extracted from the concrete dam at various points to measure the depth of carbonation. To date, 13,384 tonnes of CO_2 have been absorbed by the carbonation of the Itaipu Dam concrete [Possan *et al.* 2017]. The compressive strength of concrete is largely independent of its type, which reflects the water/cement ratio. However, the compressive strength of concrete is related to its permeability and performance in terms of carbonation and chloride penetration. Both are significantly better in industrial concrete, and this is associated with lower cement content. This trend suggests that current standards that stipulate minimum cement content requirements for durability should be revisited [Wasserman & Bentur 2006]. Permeability is related to the porosity of the concrete.

Concrete is a porous material, so air, heat, cold, humidity, water, and particles can enter it. Wind also affects the performance of concrete because it increases evaporation. The concrete surface humidity evaporation rate is an important one influencing plastic shrinkage [Papadimitropoulos et al. 2020].

Concrete pavements are affected by high and low temperatures for a long time, changing the internal pore structure and ultimately causing a decrease in the mechanical properties of concrete [Shi *et al*. 2020]. The concrete working in dry and hot climate are exposed to high temperatures in the summer. The temperature can increase up to 50 °C while the relative humidity drops to 10-15% and lower. Climatic conditions lead to decrease the performance properties such as strength and modulus of elasticity [Korovyakov *et al*. 2018]. The increase in reactivity up to 28 days occurred significantly when C_3S was initially preserved at a low temperature (20^{o}C) and then at a higher temperature (40^{o}C). The opposite happens when it is initially preserved at a high temperature and then at a low temperature [Joseph *et al*. 2017].

Indonesia is a country with high temperatures and humidity throughout the year. The average temperature and humidity throughout the year were 27^{o}C and 72% respectively [Niken *et al*. 2013]. Indonesia is also a country with high rainfall [Niken *et al*. 2019]. Unprotected concrete in the area receives heat, humidity with high fluctuation throughout the year, and rains.

The major problem inherent in using concrete in the tropical region can be traced to the corrosion of embedded steel reinforcement [Alvarado & Martinez 2008].

Thus; the study of changes in the condition of concrete that undergoes changes in temperature and humidity and its compressive strength needs to be studied.

2. Materials and Method

2.1 Materials

This research was conducted with a case study on the Basement Floor of the State University Hospital (RSPTN) of the University of Lampung in Lampung Province, Indonesia. This building has been neglected for 10 years. Part of this basement floor is protected and partly unprotected (Figure 1).


(a) (b)

Figure 1. Basement condition: (a) protected, (b) unprotected

Each condition was sampled using 4 core drills for testing the compressive strength (Figure 2).

(a) (b)

Figure 2. Drill core samples: (a) shielded, (b) unshielded

Splinters in the drill core were also taken for Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDX) tests.

2.2 Method

The compressive strength data for each condition were processed using the Dixon criteria method [ASTM E178-02 2002]. EDX was tested to determine the relationship between energy and dynamic viscosity and the relationship between atomic mass and energy.

There are four magnitudes used in the SEM test, namely 2.00K, 5.00K, 10.00K, and 15.00K. This is done so that the microstructure can be seen in its entirety. EDX and SEM results were analyzed and integrated. The result is related to the compressive strength.

3. Result

3.1 Compression strength

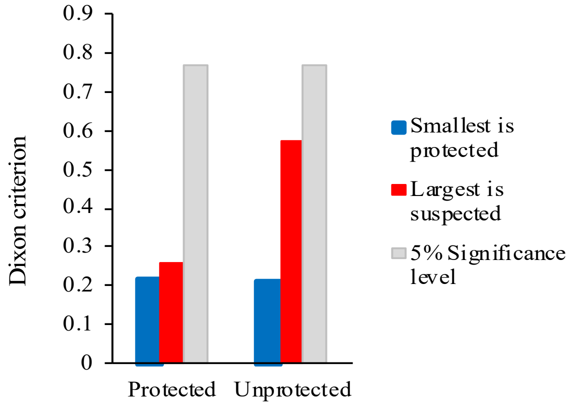


Figure 3. Examination of data

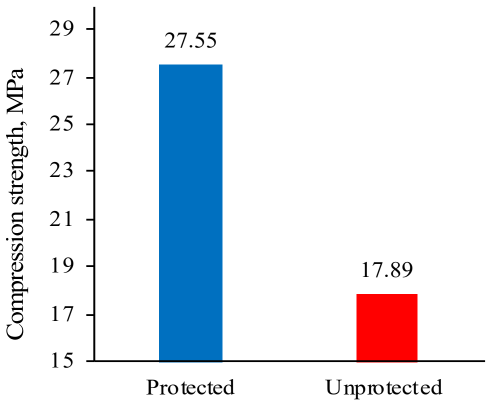


Figure 4. Compressive strength of concrete

Compressive strength data is processed by outlining method. From this processing, the largest and smallest data values for protected and unprotected concrete are below the 5% significance level. Thus; all data can be accepted (Figure 3) and compressive strength can be calculated from the average data (Figure 4).

3.2 EDX (Relationship of Energy, Dynamic Viscosity, and Atomic Mass)

The relationship between energy, dynamic viscosity, and atomic mass is presented in Figure 5.

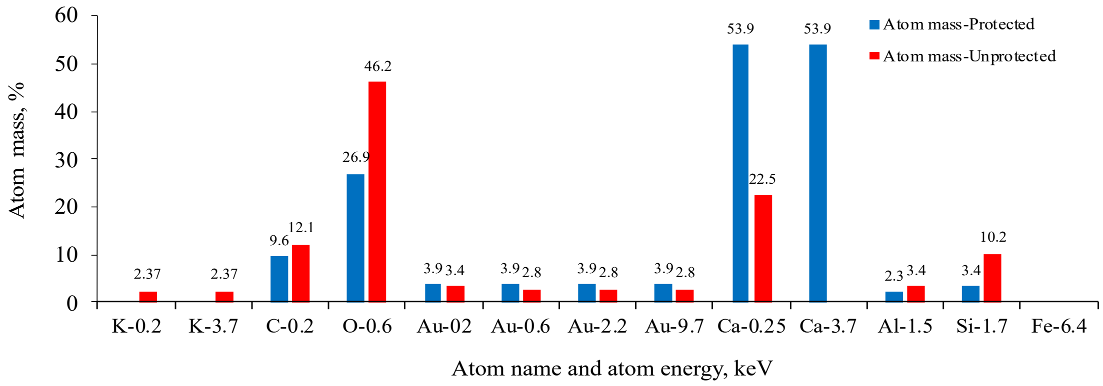


Figure 5a. EDX: atom mass, and atom energy of protected, and unprotected concrete

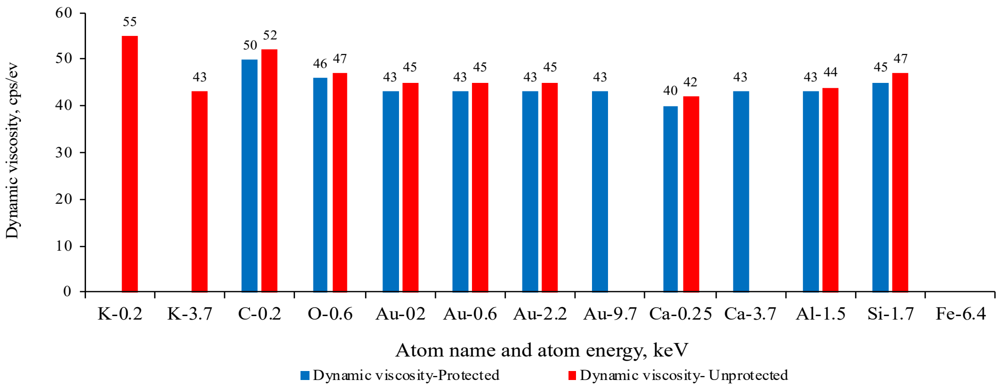
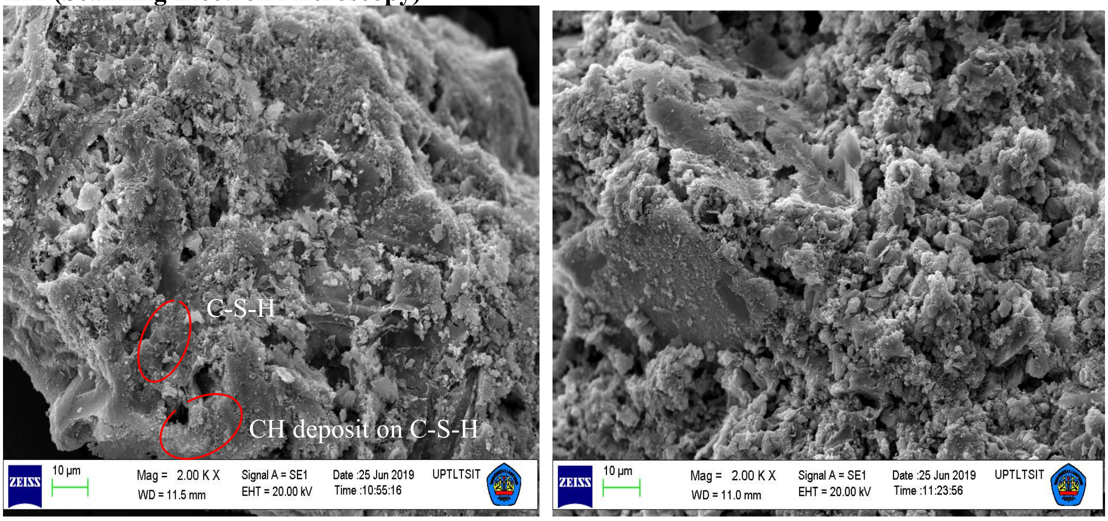


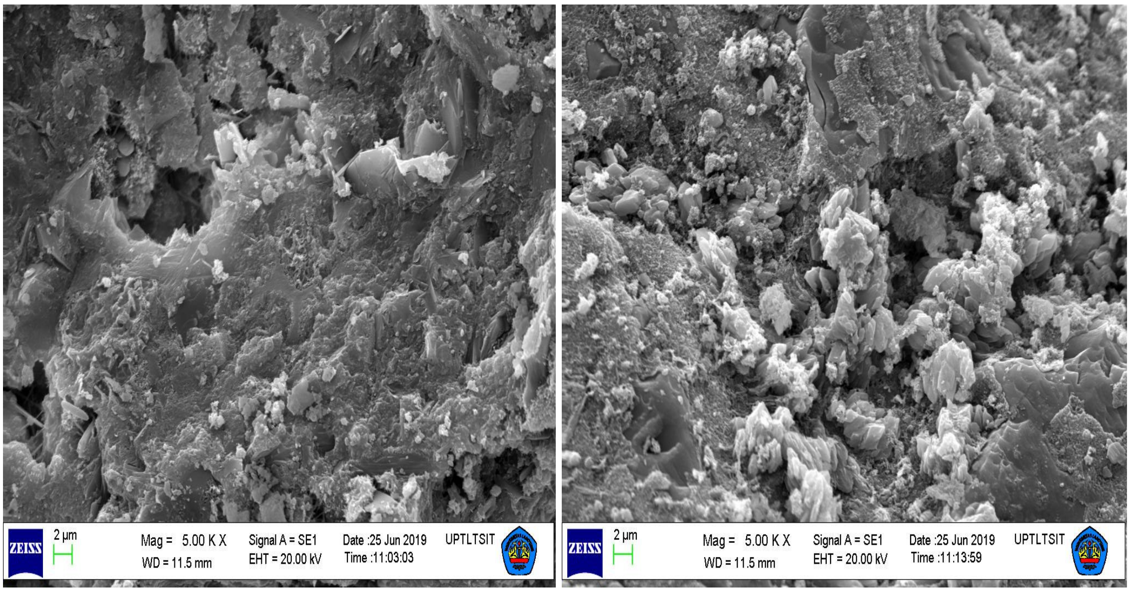
Figure 5b. EDX: Dynamic viscosity, and atomic energy of protected concrete, unprotected

3.2 SEM (Scanning Electron Microscopy)



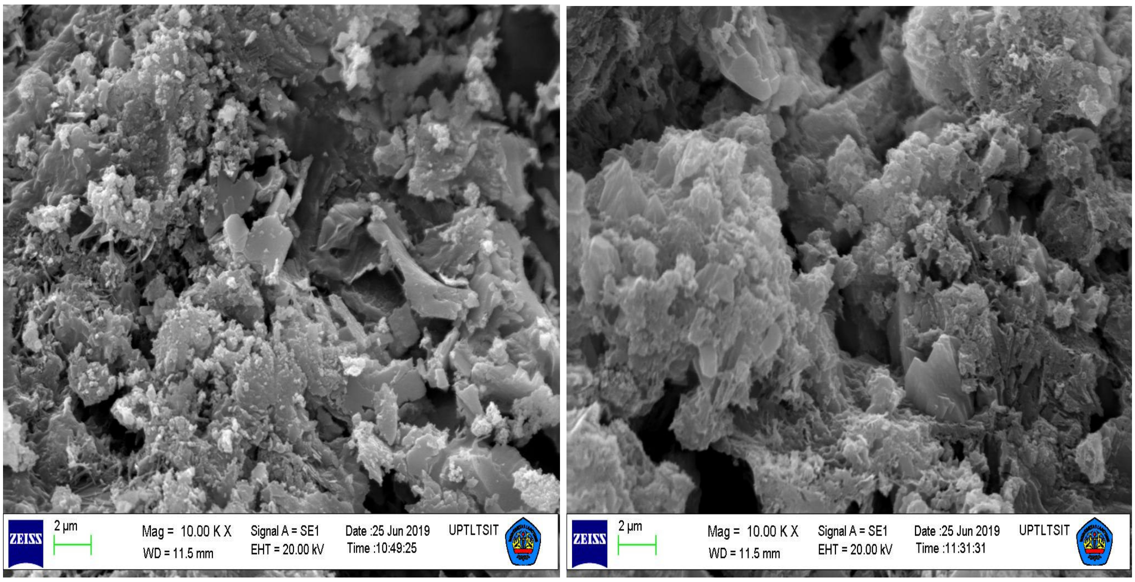
(a) (b)

Figure 6.1 SEM 2.00K: (a) Protected concrete, (b) Unprotected concrete



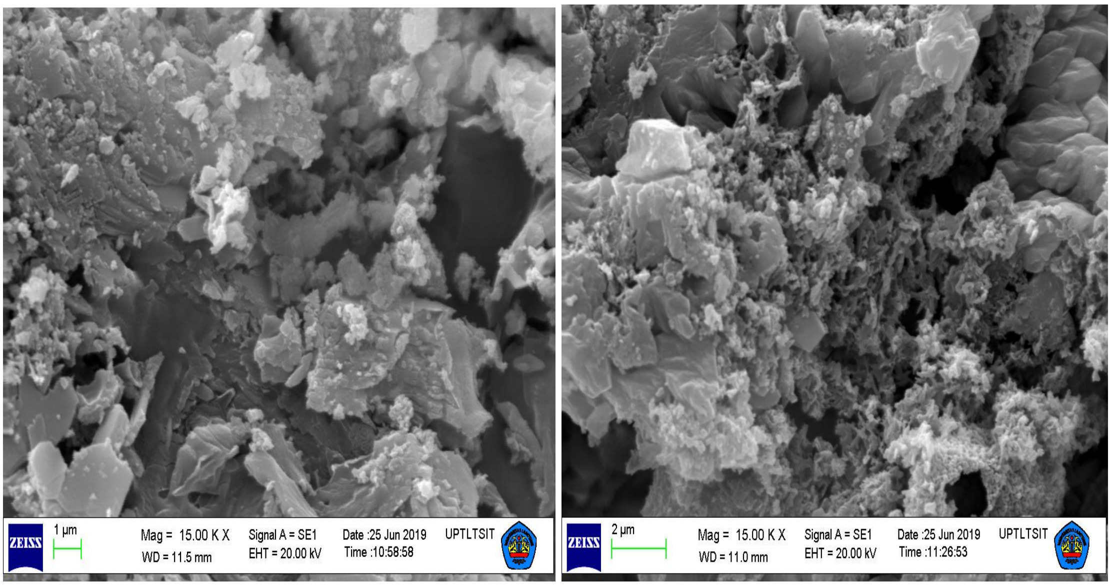
(a) (b)

Figure 6.2 SEM 5.00K: (a) Protected concrete, (b) Unprotected concrete



(a) (b)

Figure 6.3 SEM 2.00K: (a) Protected concrete, (b) Unprotected concrete



(a) (b)

Figure 6.4 SEM 2.00K: (a) Protected concrete, (b) Unprotected concrete

The differences in the microstructure of protected and unprotected concrete are presented in Table 1.

Table 1. Differences in the microstructure of protected and unprotected concrete

Magnitude	SEM view of the concrete	
	Protected	Unprotected
2.00 K	Coarse & massive, small pores	Many lumps look brittle, there are even areas, more pores, smaller and more spread out
5.00 K	CH crystals, clear CSH, very little calcite, deep visible pores	There is some rough crust covering the other parts, cracked, white lumps
10.00K	CH and CSH look very massive, with many pores and deep	Large white blobs that look brittle, deep, and numerous
15.00K	CH and CSH are very massive, with very little calcite, and deep pores	There are white lumps that are smooth, smooth areas with uneven shapes, there are nodules, there are coral-like shapes with very many pores, there are shapes like ellipses with smooth walls and look soft, and the crust is not massive.

4. Discussion

Concrete is a cement-based material formed through a chemical reaction. Concrete is a porous material. The cumulative pore volume can reach 30% [Holzer *et al*. 2006], with an area of about 500 m^2/cm^3 [Bažant & Wittmann 1982]. Unprotected concrete is concrete that is not protected against rain, sunlight and moisture. These conditions make air, water, and particles are easy to enter the concrete, react with hydration products, or react with cement that has not been hydrated, forming chemical compounds, and dissolving elements, changing the pore network. This happens continuously.

4.1 Air

Air is the easiest substance to enter the concrete. Air contains 78% nitrogen, 21% oxygen, argon, carbon dioxide, neon, helium, methane, krypton, nitrogen oxide, hydrogen, xenon, and ozone [Wikipedia 2022].

The content of rainwater depends on the origin of the water that evaporates and is carried by the wind. Rainwater can contain water vapor, nitric acid, carbon (silica and fly ash in the form of light ash), sulfuric acid, and salt [Kementerian Kesehatan RI 2017]. This compound will react with hydration products.

4.2 The mechanism of the unprotected concrete microstructure evolution

The dynamic viscosity of the elements contained in the unprotected concrete is 2 cps/eV greater than the protected elements (Figure 5b). This means that the tangential force per unit area required to move one horizontal plane to another in the unprotected concrete is greater than the protected condition.

Kalium or potassium is the only element present in unprotected concrete but not in protected concrete (Figure 5a). Potassium shows a dynamic viscosity that is almost the same as other elements found in protected and unprotected concrete.

Potassium was first isolated from potash, or plant ashes, hence Potassium is also called potassium. Potassium is an alkali hydroxide material [Sant *et al*. 2012]. Potassium in nature occurs only in ionic salts, is found dissolved in seawater, and is part of many minerals. Potassium oxidizes rapidly in air and reacts violently with water, producing sufficient heat to ignite hydrogen. Thus; the presence of potassium will increase the oxidation of unprotected concrete and generate heat, especially in the presence of hydrogen contained in the incoming air. Testing the reactivity of the supplementary cementitious material has been deemed necessary to be tested [Londono-Zuluaga 2022].

4.3 Oxidation

Most of the concrete is in contact with air. Carbon dioxide in the air reacts with calcium dioxide through the pores of the concrete as Equation 1 [Hesa 2022].

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \text{ (calcite)} + H_2O \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The atoms resulting from Equation 1 vibrate. This vibration causes a thermal expansion of calcite. At high temperatures, vacancies form because some atoms diffuse to the surface [Van Vlack 1973]. These vacancies can be filled with air, water, or potassium which is oxidized in the air or the pores of the concrete.

The increased oxidation of unprotected concrete produces more calcite, furthermore the vacancies that occur increase.

High heat due to the presence of potassium makes the particles move quickly. Calcite, C, Au, Al, and Si are in a hot environment. The heat in the concrete increases because the high temperatures of the tropics enter it. As a result, the particles move freely, vibrate and expand faster and larger. The movement of the particles can break the newly formed silica bridge due to high humidity touching the un-hydrated cement. As a result, more cavities are created due to the hydration process, vacancies, and broken silica bridges.

Therefore, it is easier for rainwater to enter it. This rainwater makes portlandite dissolve and Ca from CSH is slowly depleted. The solubility of Si increases.

With the depletion of Ca, the inner porosity of CSH becomes continuous so that the porosity increases by 17-20%, the exhausted CH makes the porosity continuous and increases by 12-15%.

Increased oxidation in the presence of potassium causes compounds with strong bases of pH 11 to 12 to decompose to bases with a pH of less than 9 [Hesa 2022]. With $pH < 10.5$, ettringite is lost. This is supported by Figures 6.1.b to 6.4.b. This pH value triggers a change in CSH. The exact decrease in CSH volume is difficult to quantify because it is a gel. The same difficulty is also in the case of portlandite crystals. The pH value < 10.5 causes CSH to collapse, break, towards the surface [Lagerblad 2001].

The thrust to the surface by the broken calcite and CSH, accompanied by heat due to Potassium and tropical temperatures causes some elements to crack (Figure 6.2.b). This crumbling CSH forms a dense silica gel layer, shrinks, the porosity increases markedly.

The pH value and high porosity make the microstructure of the unprotected concrete can be assumed to be in zone 3. The characteristics of the zone can be seen in Table 2 [Lagerblad, 2001].

Table 2. Characteristics of Zone 3 of the concrete microstructure

Phases	Zone 3	Phases	Zone 3
	Silica-gel/CSH Hydroxides		Silica-gel/CSH Hydroxides
Al_2O_3	Low	[Si] mmol/kg	1.5
MgO	Low	pH	10.0-10.5
CaO/SiO_2	0.5-1.0	Porosity	High
[Ca] mmol/kg	<4		

In the tropics countries the sun shines all day over the year, so; concrete will be drying and inner water will be evaporating. The dissolved particles dry out to form a crust (Figure 6.2.b). Sunlight and rain occur continuously, alternately. Because the pores are getting bigger and bigger, it makes the heat from the sun and rain water easier to get into the concrete. The material that occurs appears in the form of a smooth material that is pushed, layered and smooth. Other materials appear shaped like coral with many cavities. Calcite appears as white lumps that dominate the microstructure of the unprotected concrete (Figure 6.4.b).

Thus; the shape of the microstructure is more complex than protected concrete. This is following Marchand, *et al*, 1996 who states that the cement paste fraction of most dry concrete is generally much more heterogeneous than ordinary concrete.

4.4 Protected concrete

The amount of carbon dioxide that enters the normally protected concrete still does not change the microstructure of the concrete. CSH and CH or portlandite in the form of solid crystals, and ettringite dominate the microstructure of protected concrete. Apart from the hydration products, the pores are also clearly visible (Figure 6.1a, 6.2a, 6.3a, 6.4a, and Table 1). C-S-H is formed with a volume fraction containing nanometer-scale internal pores. The porosity of cement paste greatly affects its properties such as permeability, diffusion, strength, shrinkage, and elongation.

With the presence of CSH, CH, and ettringite in the protected concrete it can be said that the protected concrete is in zone 6, where Al_2O_3 is low, MgO none, CaO/SiO_2 1.6-1.7, Ca > 20 mmol/kg, Si<1 mmol/kg, pH > 12.4, very low porosity [Lagerblad 2001]. Lime or $CaCO_3$ appears as small white lumps in very small amounts compared to other hydration products (Figure 6.4a).

4.5 Calcium and Silica

In the protected condition, the concrete compressive strength mainly comes from the contribution of C-S-H and CH. Elements of Ca and Si play a major role in the quality of concrete. The atomic mass of Ca in the protected condition is 2.4 times the unshielded condition, but the atomic mass of Si is 0.33 times (Figure 5a). Ca/Si ratio is 15.85 for protected concrete and 2.2 for unprotected.

In the protected condition, there are two types of atomic energy of Ca: 0.25 and 3.7 keV, while in the unprotected condition there is only one type of atomic energy, namely 0.25 keV (Figure 5a). Based on this, the protected condition Ca is more difficult to determine than the unprotected condition.

Therefore; the Ca atom is stable. This stability makes the pores also stable so that the carbon dioxide in the air entering the concrete is limited, the movement of Si by oxidation is limited, and therefore CSH becomes stable. This makes CSH and CH also stable. This condition can be seen from the microstructure in the protected condition (Figure 6.a) which is denser with fewer pores than in the unprotected condition (Figure 6.b).

Summary

The difference between unprotected concrete versus protected concrete:

- There is potassium in the un-protected concrete
- Potassium makes the concrete temperature hotter
- Due to the greater the oxidation of potassium, the more calcite, the stronger the atomic vibration, and the pH becomes less than 9. This causes the CSH to collapse and break and then to the surface, the porosity increases.
- Heat expansion occurs by calcite and aluminum
- Direct sunlight and high temperatures throughout the year make the concrete temperature higher, the water in the concrete pores evaporates, and dries
- Rain makes portlandite and Si dissolve, and Ca from CSH is slowly depleted. Ca in unprotected concrete only has atomic energy of 0.25 eV with a mass of 22.5%, while in protected concrete there are 2 atomic energies: 0.25 eV and 3.7 eV with an atomic mass of 53.9%. Thus, Ca in unprotected concrete is easier to break or more fragile. Atomic expansion can cause brittle Ca to break up and create pores, making it more fragile.
- Thus; the element that contributes to the main strength of concrete is greatly reduced.

- The rainy season alternates with the dry season. The Ca solution, and the precipitate, which occurs are formed gradually (Figure 6.4.a).

The forces that arise in unprotected concrete include the particle motion force due to heat, atomic vibration, expansion force, the force that breaks down and breaks CSH, the portlandite soluble force, and the Si soluble force. This makes the dynamic viscosity of all compounds contained in the unprotected concrete greater. This force penetrates the more porous and more brittle material so that the bonds are broken, the pores become more continuous, and the concrete microstructure becomes more complex.

5. Conclusion

The presence of an element that triggers oxidation and the presence of water makes unprotected concrete more fragile. The strength of the concrete decreases to 65% of the compressive strength of the protected concrete or 17.89 MPa while in the protected condition it is 27.55 MPa.

References

Alvarado, J. & Martinez, E. (2008), "Passive Cooling of Cement-Based Roofs in Tropical Climates". *Energy and Building Journal* **40** (3), 358-364.

ASTM International (2019), *ASTM D7031-11: Standard Guide for Evaluating Mechanical and Physical Properties of Wood-Plastic Composite Products.* West Conshohocken, Pennsylvania: ASTM International.

Bažant, Z.P. & Wittman, F.H. (1982) *Creep and Shrinkage in Concrete Structures*. John Wiley & Sons, Inc., New York, Chapter 7, 129 – 161.

Hesa Laras Cemerlang Ltd (2022), *Korosi pada Beton Bertulang*, Available from: https://hesa.co.id/korosi-pada-beton-bertulang/ [Accessed 26/05/22]

Holzer, L., Gasser, P. & Muench, B. (2006), "Quantification of Capillary Pores and Hadley Grains in Cement Paste Using FIB-Nanotomography: Measuring, Monitoring and Modeling Concrete Properties", 2nd *International Symposium on Advance in Concrete through Science and Engineering*. Springer, Quebec City, Canada, Sept, pp. 509-516.

Joseph, S., Bishnoi, S., Van Balen, K. & Cicer, O. (2017), "Effect of the Densification of C-S-H on Hydration Kinetics of Tricalcium Silicate". *Journal of the American Ceramic Society* **101** (6), 2438-2449.

Kementrian Kesehatan Republik Indonesia. (2017), *Kandungan Zat Kimia yang Terdapat pada Air Hujan.* [online]. Pusat Krisis Kesehatan. Available from:
https://pusatkrisis.kemkes.go.id/kandungan-zat-kimia-yang-terdapat-pada-air-hujan [Accessed 27/05/22]

Korovyakov, V., Reshetneva, P. & Solovyov, V. (2018), "Mechanical Properties of Hardened Concrete in Hot and Dry Climate", *IOP Conf. Series: Materials Science and Engineering*, **365** (032037),1-6.

Lagerblad, B. (2001), "Leaching Performance of Concrete Based on Studies of Samples from Old Concrete Construction", Svensk Kärnbränslehantering AB Swedish Nuclear Fuel and Waste Management. Stockholm Sweden, Technical Report TR-01-27, 1-83.

Londono-Zuluaga, D., Vayghan, A.G., Winnefeld, F.& Scrivener, K.L. (2022). "Report of RILEM TC 267-TRM phase 3: Validation of the R3 Reactivity Test Across a Wide Range of Materials. Materials and Structures", **55** (5). DOI: 10.1617/s11527-022-01947-3

Marchand, J., Hornain, H., Diamond, S., Pigeon, M. & Guiraud, H. (1996), "The Microstructure of Dry Concrete Products", *Cement and Concrete Research Journal* **6**(3), 427-438.

Niken C., Elly, T., Supartono, F.X. (2013), "Long-term Shrinkage Empirical Model of High- Performance Concrete in Humid Tropical Weather". *Journal Civil and Environmental Research* **3** (2), 35-46.

Niken, C., Heriyanto, A.T., Rahayu, S., Karami, M. & Putra, S. (2019), "Penggunaan IRI dan SDI dalam Menentukan Perbaikan Cacat Lubang pada Perkerasan Lentur di Daerah Tropis dengan Curah Hujan Tinggi", In: *Proceeding of the National Seminar SINTA Faculty of Engineering University of Lampung Indonesia, Tantangan dan Peluang Riset Perguruan Tinggi untuk memenuhi Kebutuhan Dunia Industri Berkelanjutan*", *Sept 2019*, Bandar Lampung, Indonesia, 2, 149-157.

Papadimitropoulos, V.C., Tsikas, P.K., Chassiakos, A.P. (2020), "Modeling the Influence of Environmental Factors on Concrete Evaporation Rate", *Journal of Soft Computing in Civil Engineering* **4** (4), 79-97.

Plidek. (2019), "UV Damage: The Hidden Danger to Concrete and Wood", Available from: https://plidek.com/uv-damage-concrete-wood-masonry/

Possan, E., Thomas, W.A., Aleandri, G.A., Felix, E.F., Dos Santos, A.C.P. (2017), "CO_2 Uptake Potential due to Concrete Carbonation: A Case Study". *Case Studies in Construction Materials Journal* **6**, 147-161.

Sant, G., Kumar, A., Patapy, C. & Scrivener, K.I. (2012), "The Influence of Sodium and Potassium Hidroxyde on Volume Changes in Cementitious Materials", *Cement and Concrete Research Journal* **42** (11), 1447-1455.

Shi, J., Zhao,Y. & Zeng, B. (2020), "Relationship Between Pore Structure and Bending Strength of Concrete under a High-Low Temperature Cycle Based on Grey System Theory". *The Journal of Grey System* **32**(4), 7,907 words.

Soudian, S., Berardi, U. & Laschuk (2020), “Effects of Long-term UV Exposure on the Performance of Cement Plasters Integrated with Thermochromic Paint and PCMs for Building Façade Application”, In: *XV International Conference on Durability of Building Materials and Components, Barcelona*, Oct 2020. Barcelona, 1-8.

Van Vlack, L.H. (1973), “*Materials Science for Engineers*”, Fourth printing, Michigan: Addison Wesley, 4, USA.

Wasserman, R. & Bentur, A. (2006), “Effect of Concrete Composition on Durability in Natural Acidic Environment”. *Advances in Cement Research Journal* **18** (4), 135-143.

Wikipedia. (2022), *Composition of air*. [online] Atmosphere, Air, and Gases. Available from:https://mccord.cm.utexas.edu/chembook/page.php?chnum=2&sect=1[Accessed 27/05/22]